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Use of a modified GIS-based Environmentally Sensitive Areas index (ESAI) to evaluate desertification risk in rangelands of northern Greece

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ABSTRACT

The aim of this study was to evaluate the desertification risk of rangelands in three village communities of Lagadas county, northern Greece, with the use of the Geographic Information Systems (GIS). Geoinformation data were used in order to combine several layers of information involved in desertification for the formation of a GIS model. The latter is a modified approach of the methodology used for mapping Environmentally Sensitive Areas (ESAs). It is found that the majority of the study area is in a critical stage in terms of desertification. The majority of rangelands are under intensive grazing activities. Overgrazing however, contributes to the desertification risk in combination with physical parameters such as soil, vegetation and climate.

Keywords: Desertification, Greece, Lagadas, Indicators, GIS.

1 INTRODUCTION

Desertification is a complex issue, closely related with land degradation and is caused by both human and physical forcing functions [1, 2, 3]. Among other definitions, the most recent and generally accepted is the one proposed by the Convention to Combat Desertification as "*land degradation in arid, semi-arid and dry sub-humid areas resulting from climatic variations and human activities*" [4].

In the Mediterranean region, desertification is not a new phenomenon. Historically, this region has had widespread problems because of intense land degradation [3]. In the northern part in particular, dryland regions are suffering desertification on a wide scale due to human activities in combination with harsh climatic conditions [4]. Several areas in Greece are threatened by desertification with most notable examples the islands of Lesvos [5] and Crete [6].

The Greek National Action Plan for Combating Desertification [7] lists as main factors of desertification the following: climate, physiography, geology, soil, hydrology and the human effects. Separately, the first five physical factors do not cause desertification, unless they are combined with irrational human practices. Furthermore, desertification is attributed to socio-economic factors, which can be expressed by several key indicators [8, 9, 10, 11].

Remote Sensing and GIS can be used either alone or in combination for the estimation of desertification risk [12, 13, 14] by employing special assessment models [14, 15, 16, 17]. The objective of this research was to estimate the environmental sensitivity of rangelands to desertification in three representative village communities of northern Greece as well as to identify which factors are critical for each of these communities.

2 MATERIAL AND METHODS

2.1 Study Area

The research was carried out in Lagadas county located about 30 km NE of the city of Thessaloniki, in Macedonia, northern Greece. Livestock husbandry is an important economic activity in the area and livestock have slightly increased in numbers over the last years [18].

Three village communities, namely Kolchiko, Lofiskos and Kryoneri (Fig. 1), were chosen as study area. Each village is located at different altitude, i.e. at the low (0-200 m.), middle (200-600 m.) and high (>600 m.) elevation zones respectively. All communities are located above the Koronia lake, and cover a total area of 14619.78 ha (3537.54 ha, 5237.37 ha, 5844.87 ha for each one respectively without urban areas). They have been studied by the European research projects GeoRange (Contract no. EVK2 -2000 - 22089) and VISTA (Contract no.EVK2 - 2001 -

000356) for the years 2001-2005 and the national research project Pythagoras (Contract no. 21893) for the years 2004- 2006.
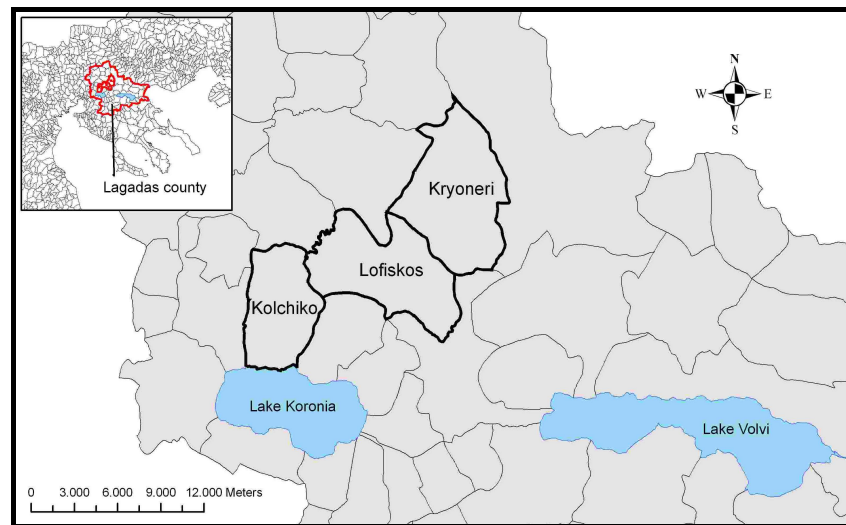

Figure 1. Map of the study area.

2.2 Methodology

Geoinformation data were used in order to combine several layers of information (physical, ecological and economic) involved in desertification for the formation of a GIS model. This model is a modified approach to the methodology used for mapping Environmentally Sensitive Areas (ESAs) in the MEDALUS project [14]. The modification can be found in the use of a reduced number of information layers as some layers were excluded from the model and some others were differently calculated e.g. stocking rate or added e.g. distance from sheds.

To determine the quality maps, data that were prior digitized and processed for the needs of the European project GeoRange were used. They included indices for climate quality, soil quality, vegetation quality and management quality. These indices were given weighted scores to emphasize or not the relative importance of information layers according to MEDALUS methodology (Table 1).

Soil quality: The parent material categories of the geology map [19] were regrouped into larger ones and the scores were given according to the MEDALUS methodology, as well as to the characteristics of the soil. The soil depth categories were derived from the soil map of Greece [20] and expressed in cm (Table 1). The slope was derived from the digitized contours of the topographic map of Greece (Hellenic Military Geographical Service, scale 1:50000).

Climate quality: The mean annual precipitation was estimated from the linear relation between precipitation and elevation [21]. This was done due to the fact that no meteorological stations existed in study area, and five nearby but located at different altitudes were used instead. The equation (1) between precipitation (Y) and altitude (X) produced was

$$Y=0.3272 X+434.78 \qquad R^2 =0.573, \quad p<0.05. \qquad (1)$$

Slope aspect was the second layer used for climate quality and derived from the digitized contours of the topographic map of Greece (Hellenic Military Geographical Service, scale 1:50000).

Vegetation quality: Vegetation quality was estimated from the land cover/use categories of the orthophotomaps of the Greek Forest Service (scale 1:20000). In this classification, all kinds of agricultural land are grouped as one unit. For this reason, the CORINE land cover database [22] was used in addition, in order to determine the type of agricultural use. According to the GeoRange [18], at least 80% of the arable lands in Lagadas county is grown with cereals crops (annual). Also the majority of grasslands of the area are perennial. Finally, woody cover data were used for denoting plant cover.

Table 1. Quality indices with their relative information layers and scores.

Quality	Information layers	Classes		Scores
Soil	Parent material	Deposits, Ultra basic, Molasses of Lagadas		1
		Gneiss, Granite, Quartzite		1.7
	Soil depth (Description coded in soil map of Greece and in MEDALUS project).	Deep	Deep (>75 cm)	1
		Deep and shallow, Deep and bare	Moderate (75-30 cm)	2
		Shallow and deep, Shallow, Shallow and bare, Bare and deep	Shallow (15-30 cm)	3
		Bare and shallow, Bare	Very shallow (<15 cm)	4
	Slope (%)	<6		1
		6-18		1.2
		18-35		1.5
		>35		2
Climate	Rainfall (mm/year)	> 650		1
		280-650		2
		< 280		4
	Slope aspect	North, NW, NE, plain		1
		South, SW, SE		2
Vegetation	Fire risk	Barren land, Olives		1
		Abandoned agricultural land, Annual agricultural crops, Grasslands, Deciduous forests (oak, mixed)		1.3
		Shrublands		1.6
		Conifers		2
	Erosion protection	Conifers, Shrublands, Grasslands, Olives		1.3
		Deciduous forests (oak, mixed)		1.6
		Barren land, Annual agricultural crops, Abandoned agricultural land		2
	Drought resistance	Barren land		1
		Conifers, Deciduous forests, Olives		1.2
		Shrublands, Grasslands		1.7
		Annual agricultural crops, Abandoned agricultural land		2
	Woody plant cover (%)	> 40		1
		10 -40		1.8
		<10		2
Management	Stocking rate (AUM/ha)	<0.5		1
		0.5 – 2.5		1.5
		> 2.5		2
	Distance from sheds (m)	0-150		2
		150-400		1.8
		>400		1

Management quality: The management quality map was created from the point view of land use intensity, considering only stocking rate and the piospheric impact of animal sheds. Stocking rate was expressed in animal units per unit area, i.e. by dividing the number of free grazing animal units of each village community separately with the area of rangelands, derived from the forest orthophotomaps (scale 1:20000) that were corrected in 2002 [23]. For the calculation of stocking rate, sheep and goats raised in flocks, as well as the free grazing cows which are totally depending on rangelands were considered as well as. The grazing units were expressed in sheep equivalents (1 sheep or 1 goat or 5 sheep for each cow) [18].

Animal sheds have a piospheric impact on woody cover and plant height within a zone smaller than 800 m [24]. In Ref. [25] also was found that different plant heights of shrubs in the study area correlate with different biomass production and woody cover. Taking into account these two findings and the results from linear regression analysis of woody plant cover and plant height with the distance from the sheds [24], a strong reduction of the woody cover in the first 150 m was found and then a moderate one up to 400 m.

The computing algorithms, expressed with Eqs. (2) and (3) were calculated to produce the quality and desertification risk maps for each village community as described in Ref. 13 and 14.

$$\text{Quality\_x}_{ij} = (\text{layer\_1}_{ij} * \text{layer\_2}_{ij} * \text{layer\_3}_{ij} * \ldots * \text{layer\_n}_{ij})^{(1/n)}, \tag{2}$$

where: i,j = rows and columns of a single elementary pixel (30 x 30 m) of each layer; n = number of layers used and

$$\text{ES}_{ij} = (\text{Quality\_1}_{ij} * \text{Quality\_2}_{ij} * \text{Quality\_3}_{ij} * \text{Quality\_4}_{ij})^{(1/4)}, \tag{3}$$

where: i,j = rows and columns of a single elementary pixel (30 x 30 m) of each quality; Quality_n_{ij} = computed values.

Subsequently the available digital data from the GeoRange project were introduced into the GIS softwares, ArcGIS Desktop 9.0 and ArcInfo Workstation 9. In order to depict the physiographic characteristics of the area, the Digital Elevation Model (DEM) was created and the slope and exposure maps were derived. The 20 m spacing contour line used for the creation of the DEM was corrected with the "topogrid" command of the ArcInfo Workstation 9 in order to make a hydrologically correct model. The topogrid command is an interpolation method specifically designed for the creation of hydrologically correct digital elevation models (DEMs) from comparatively small, but well selected elevation and stream coverages [26]. The animal shed impact layer was processed with the Spatial Analyst tool (ArcGIS 9). The remaining digital vector data sets (shapefiles and coverage) were also processed with the Spatial Analyst tool (ArcGIS 9) to convert them into a grid format. This grid format had a minimum pixel size of 30 m, which is considered to be a satisfactory size for the land surface research [27]. Finally, the computing algorithm of all information layers in grid format was combined with the "raster calculator" command, resulting in the quality and desertification maps.

3 RESULTS AND DISCUSSION

Four quality maps were produced (Fig. 2). The majority of the study area (78.75%) has low vegetation quality with respect to desertification risk followed by moderate quality (21.25%). The absence of high quality class is probably due to the dominance of annual crops in terms of cover and to the presence of very low cover of woodlands. The large annual crop cover results in low erosional protection and very low drought resistance (annual crops in Mediterranean vegetation are classified in the less drought resistance category). Almost 52.55% of the area is covered by rangelands, from which 30.39% are shrublands and open forests with moderate cover (10-40%), while 11.28% is covered by perennial grasslands. The vegetation quality improves (from low to moderate) where dense deciduous forests (oaks) and shrublands (23.78% in total) occur.

Soil quality is predominantly low (67.09%) in the area. The greatest part has a shallow soil depth (54%), steep slopes (21.36%) and gneiss rocks up to 72%. The remaining part has high (17.28%) to moderate (15.63%) soil quality which is attributed to the gentle slopes (over 45%) and tertiary deposits (18%).

The climate quality is low (63.76%) due to the extended cover (over 70%) of the S, SE and SW slopes aspect of the area. The mean annual precipitation is over 556 mm in 83% of the area, while the remaining part, mostly located in higher elevation zone, has a mean annual precipitation of over 650 mm.

Finally, high management quality was found in the 68.86% of the area, and moderate in 25.65%. However, over 55.24% of rangelands have moderate management quality because of overgrazing and only 33.13% have high
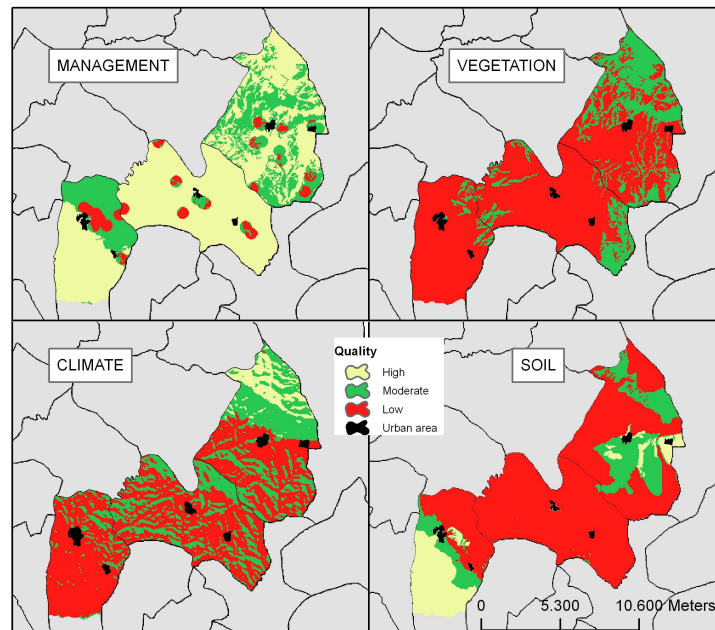
Figure 2. Quality maps of the study area.

quality due to moderate grazing. Low management quality is restricted to 11.63% of rangelands which is attributed to the piospheric impact of animal sheds.

The final map of ESAs (Fig. 3) was derived according to indices ranges, as described by MEDALUS project. The types of ESAs are defined as critical (C), fragile (F), potential (P) and non affected (N). Furthermore, the critical and fragile areas are defined on a three-point scale ranging from 3 (high sensitivity) to 1 (lower sensitivity). The map of the ESAs indicated as critical the major part of the three village communities (88.03%), followed by fragile (8.31%) and potential (1.51%). Only 2.15% of the area is not affected (N) by desertification because of deep soils and dense deciduous forests. The description of ESAs of the study area is:

Critical ESAs: Areas with gentle to very steep slopes with shallow to moderate soil depth on gneiss and granite parent material and tertiary deposits. The rainfall is generally <650 mm. Areas of this subtype are found in south-facing and in cases north facing slopes. The dominant vegetation is shrublands with low cover (10-40%), grasslands and cereals (<10%). These areas sustain husbandry, and stocking rate varies from high (Kolchiko and Kryoneri) to moderate (Lofiskos). In addition, areas around animal sheds are threatened from the piospheric impact. The use of woody cover indicator instead of plant cover probably increased the percentage of critical ESAs, especially in areas with woody cover lower than 10%, e.g. grasslands and cereals.

Fragile ESAs: Areas located mainly at Kryoneri village with steep to gentle slopes and in cases very gentle to flat, with shallow to deep soils. They formed mainly gneiss parent materials. Precipitation height is higher than 650 mm in the northern areas of Kryoneri, while it turns to moderate (less than 650 mm) in the remaining area. These areas are mainly found in south-facing slopes and in some cases in north-facing slopes. The dominant vegetation is deciduous forests with moderate cover (40-70%) to high (70-100%) and cereals (<10%). These areas are experienced mild grazing activities and are not threatened from the piospheric impact of animal sheds.

Potential ESAs: These areas are located only in Kryoneri with moderate soil depth and gneiss rocks with gentle to steep slopes. They are found on north-facing slopes or they are flat, with high rainfall >650 mm. The dominant vegetation is dense (>70%) deciduous oak forests with moderate fire risk, erosion protection and resistance to drought. Grazing activities are restricted and animal sheds are far away.

Non threatened areas: These areas are located only in Kryoneri village community with the same characteristics of potential ESAs but with deep soils.

Over 90% of Kolchiko (Fig. 4) is characterized by critical environmental sensitivity to desertification because of low vegetation quality (94.54%), attributed to the high percentage of annual crops and the moderate woody cover of shrublands in the north side of the village. Areas with fragile sensitivity are restricted (2.44%) to where dense shrublands occurs. Also rangelands have low woody cover and moderate management quality (up to 80%) because of overgrazing (stocking rate 3.39).
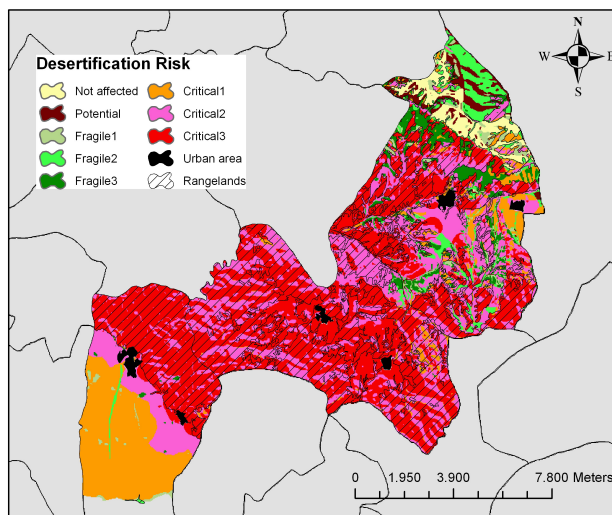
Figure 3. Environmental Sensitive Areas of the three village communities.

The village also has very low climate quality, because of the dominance of S, SW and SE slope aspects (86.07%). The mean annual precipitation is over 500 mm (<650mm). Tertiary deposits occupy more than 60% indicating a high soil quality (45.86%); they are mostly located above the Koronia lake. Also, there is deep and very gentle to flat soil. However, in the north side of the village where gneiss occurs (over 30%), the depth is shallow and the slope steep, the soil quality is low. The soil quality becomes moderate in the middle of the village community because the soil has moderate depth and gentle slope.

The whole Lofiskos indicates critical environmental sensitivity to desertification. There is very low soil quality (over 99%) because of very shallow soils. Gneiss cover more than 87% and granite only 11.33%. Slope is gentle with a percentage over 60%. In cases where there are ultra basic rocks and deposits, the soil quality becomes moderate. The vegetation quality is low (over 80%) and becomes moderate (over 16%) in the east part of the village and in cases in the west part. Low vegetation quality is the result of moderate woody cover of shrublands (over 40%) and the low woody cover of the grasslands. There is high management quality (over 90%) due to moderate stocking rate (1.36) in rangelands. The village has low (over 60%) to moderate climate quality (over 37%), because of the N, NW and NE aspects and the mean annual precipitation is over 550 mm (<650mm).

Kryoneri showed over 65% of its area with critical environmental sensitivity to desertification (south part) and the north part (over 20% of its area) with fragile environmental sensitivity. About 6% of the village is not affected and over 4% is potential. Low soil quality has the greatest impact on desertification (63.79%). Gneiss covers more than 80% and granite only 12.28%. In places where the soil depth is moderate to shallow the soil quality is low. Slope is very gentle to flat in the center of the village and rises from gentle to steep as we move to the margins. The soil quality becomes high in parts of the area where deep soil is found and the slope is gentle with tertiary deposits (5.97%). The vegetation quality is low (58.57%) in the south part of the village and moderate in the north. Low vegetation quality is the result of the low woody cover (over 10% of the shrublands and 10% of the forests). The village has moderate to low climate quality in the south because of S, SW and SE slopes and precipitation up to 600 mm. In the north, where N, NW and NE aspects occurs and the mean annual precipitation is up to 700 mm, the quality is high. In the lower part of the village and especially in the center of it the climate quality becomes low and in some places moderate, according to the exposure. Kryoneri has high management quality (55.10%). However, rangelands which represent the 40% of the area are overgrazed (stocking rate 4.87), resulting to moderate management quality.
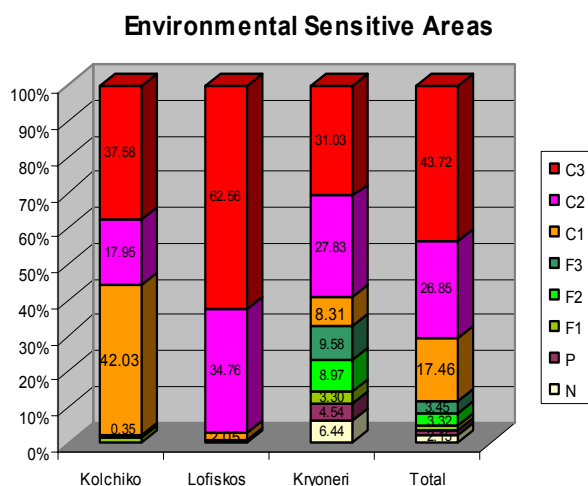
It is obvious that the three village communities have areas with critical environmental sensitivity to desertification. Desertification risk in the area is the result of the interaction of all parameters studied. Despite the intensive grazing activities, management quality is low only around animal sheds, because of the piospheric impact of animal sheds. The most sensitive village communities are Lofiskos and Kolchiko because of low soil quality and low vegetation quality respectively. Kryoneri has high desertification risk because of low soil quality.

Figure 4. Percentages of ESAs of the three village communities, separately and as total.

4 CONCLUSIONS

It is crucial to estimate the environmental sensitivity of areas at a local scale, so that we have a real estimation of desertification risk. The methodology used in the MEDALUS project provides the ability to add or remove information layers, according to available data, and making ESAI an important index in desertification risk assessment. Unambiguously, the proposed simplified GIS model can manage easily obtained data, but can be significantly improved if more information layers related to desertification are added.

Rangelands, especially in Kolchiko and Kryoneri village communities are in critical desertification stage mainly due to intensive grazing activities. The use of woody cover indicator instead of plant cover probably increased the percentage of desertification risk, especially in areas with woody cover lower than 10%. Finally overgrazing results in desertification in combination with other parameters related to desertification. However, piospheric impact of animal sheds had a critical effect in management quality, although restricted around the sheds.

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